

Heavy quark correlations in hadronic collisions

Marta Łuszczak*

University of Rzeszów, ul. Rejtana 16c

PL-35-959 Rzeszów, Poland

E-mail: luszczak@univ.rzeszow.pl

Antoni Szczurek

Institute of Nuclear Physics, PL-31-342 Cracow, Poland

and University of Rzeszów, PL-35-959 Rzeszów, Poland

E-mail: Antoni.Szczurek@ifj.edu.pl

We discuss results of the k_t - factorization approach for heavy quark-heavy antiquark correlations in proton-proton and proton-antiproton collisions for RHIC, Tevatron and LHC. We consider correlations in the azimuthal angle as well as in the two-dimensional space of transverse momentum of heavy quark and heavy antiquark. We compare results obtained with the help of different unintegrated parton distributions (UPDF) from the literature.

High- p_T physics at LHC

March 23-27 2007

University of Jyväskylä, Jyväskylä, Finland

*Speaker.

1. Introduction

The heavy quark-antiquark hadroproduction is known as very important test of conventional gluon distributions within a standard factorization approach. Standard collinear approach does not include transverse momenta of initial gluons. The method to include transverse momenta is k_t -factorization approach [1, 2, 3]. At the leading order of the collinear approach the heavy quark and heavy antiquark are produced back-to-back. In the unintegrated parton distributions (UPDF) approach [4, 5, 6], the azimuthal angle and p_t decorrelations (from the collinear leading-order configurations) are obtained already in the leading order of perturbative expansion [7]. In Ref.[7] we have explored in detail $c\bar{c}$ kinematical correlations at the Tevatron energies. Here we wish to discuss a more general case of (heavy quark)-(heavy antiquark) correlations for the RHIC, Tevatron and LHC energy range. We wish to emphasize that this is not yet well explored field of high-energy physics which could and should be studied in the future, in particular at LHC.

2. (Heavy quark)-(heavy antiquark) correlatons

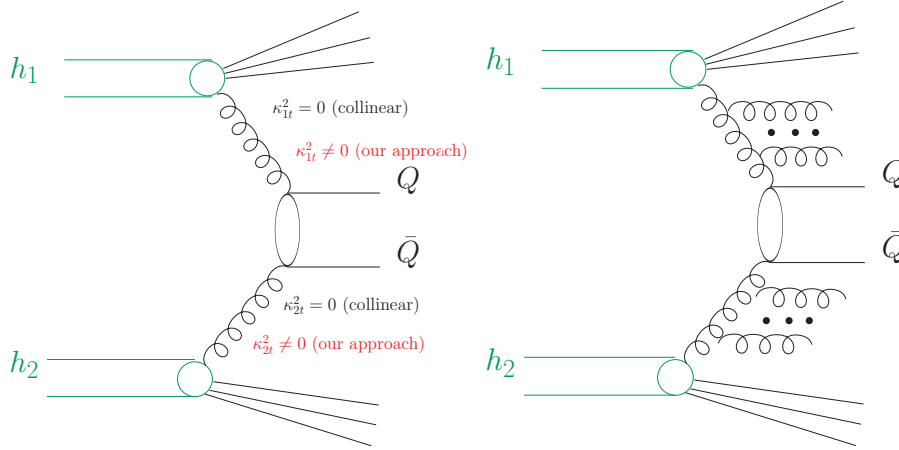


Figure 1: Typical diagrams for heavy quark - antiquark production.

Let us consider the reaction $h_1 + h_2 \rightarrow Q + \bar{Q} + X$ (see Fig.1), where Q and \bar{Q} are heavy quark and heavy antiquark, respectively. In the leading-order k_t -factorization approach the cross section in rapidity of Q (y_1), in rapidity of \bar{Q} (y_2) and transverse momentum of heavy quark ($p_{1,t}$) and heavy antiquark ($p_{2,t}$) can be written as

$$\frac{d\sigma}{dy_1 dy_2 d^2 p_{1,t} d^2 p_{2,t}} = \sum_{i,j} \int \frac{d^2 \kappa_{1,t}}{\pi} \frac{d^2 \kappa_{2,t}}{\pi} \frac{1}{16\pi^2 (x_1 x_2 s)^2} |\overline{\mathcal{M}}_{ij}|^2 \delta^2(\vec{\kappa}_{1,t} + \vec{\kappa}_{2,t} - \vec{p}_{1,t} - \vec{p}_{2,t}) f_i(x_1, \kappa_{1,t}^2) f_j(x_2, \kappa_{2,t}^2), \quad (2.1)$$

where $f_i(x_1, \kappa_{1,t}^2)$ and $f_j(x_2, \kappa_{2,t}^2)$ are so-called unintegrated parton distributions. The two extra factors $1/\pi$ attached to the integration over $d^2 \kappa_{1,t}$ and $d^2 \kappa_{2,t}$ are due to the conventional relation between unintegrated and integrated parton distributions. The two-dimensional delta function assures momentum conservation.

The unintegrated parton distributions must be evaluated at: $x_1 = \frac{m_{1,t}}{\sqrt{s}} (\exp(y_1) + \exp(y_2))$, $x_2 = \frac{m_{2,t}}{\sqrt{s}} (\exp(-y_1) + \exp(-y_2))$. The matrix element must be calculated for initial off-shell partons. The corresponding formulae for initial gluons were calculated in [1, 2] (see also [3]). In our paper we compare results obtained for both on-shell and off-shell matrix elements for charm-anticharm correlations.

3. Results

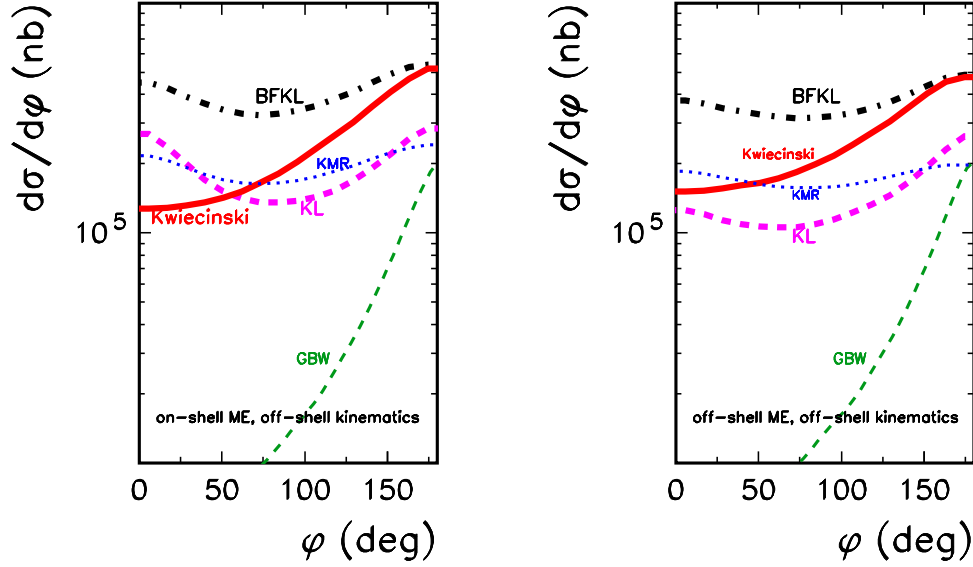


Figure 2: $d\sigma/d\phi$ for charm - anticharm production at $W = 1960$ GeV for different UGDFs. The results with on-shell kinematics are shown in the left panel and results with off-shell kinematics in the right panel. In this calculation both factorization and renormalization scales were fixed for $4 m_c^2$.

In Fig.2 we compare results for different unintegrated gluon distributions from the literature. Different results are obtained for different UGDF. BFKL dynamics leads to strong decorrelations in azimuthal angle between charm and anticharm quarks. In contrast, the nonperturbative GBW glue leads to strong azimuthal correlations between c and \bar{c} . The saturation idea inspired KL distribution leads to an local enhancement for $\phi_{c\bar{c}} \approx 0$ which is probably due to simplifications made in parametrizing the KL UGDF. In the last case there is sizeable difference between the result obtained with on-shell (left panel) and off-shell (right panel) matrix elements. All this is due to an interplay of the matrix element and the unintegrated gluon distributions.

In Fig.3 we show results for correlations in $(p_{1,t})$ of c and $(p_{2,t})$ of \bar{c} for different unintegrated gluon distributions. Our results depend strongly on different UGDF. This is very interesting, because it can be verified in future experimental studies.

In Fig.4 we show another type of two-dimensional distribution. Generally, the bigger transverse momentum of the produced quark (or antiquark) the stronger back-to-back correlation in

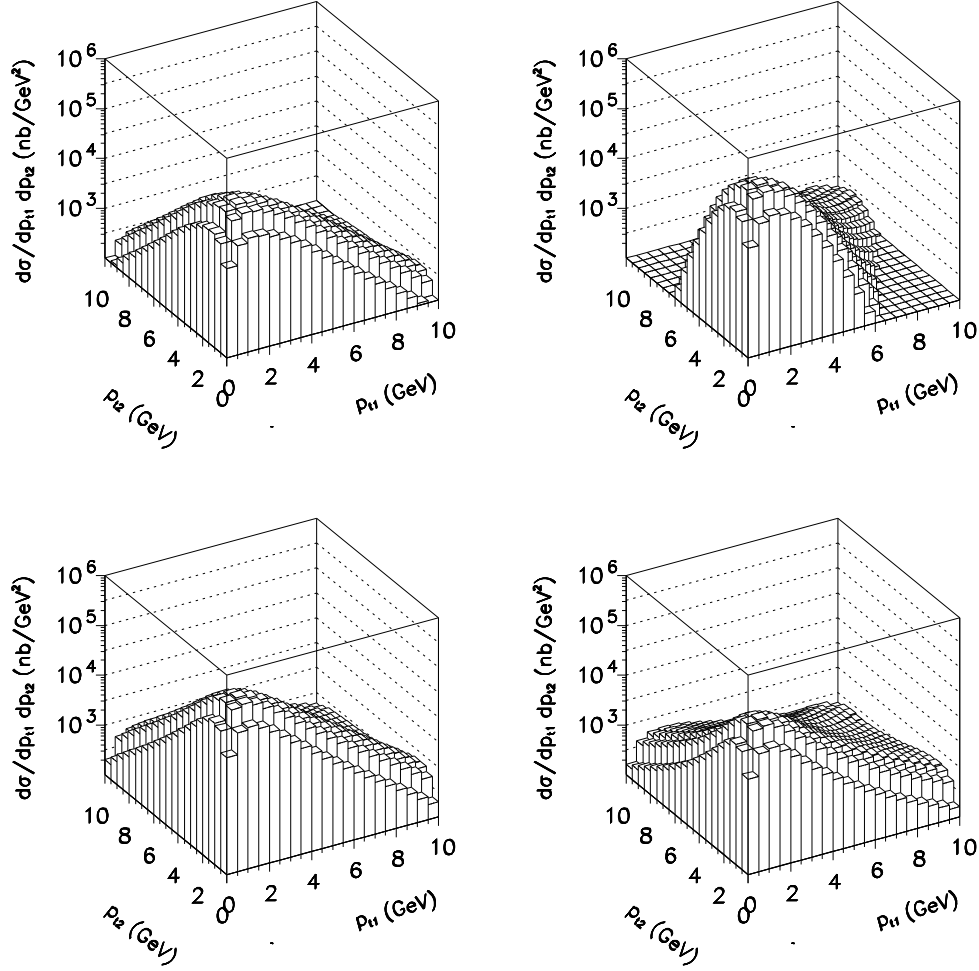


Figure 3: Two dimensional distributions in $(p_{1,t})$ of charm quark and $(p_{2,t})$ of charm antiquark for KMR, Kwieciński ($b_0 = 1 \text{ GeV}^{-1}$, $\mu^2 = 10 \text{ GeV}^2$), BFKL, KL UGDFs for $W = 1960 \text{ GeV}$.

azimuth. Similarly as in the previous case, the results depend on UGDFs used in the calculation. The somewhat stronger back-to-back correlation in the case of the Kwieciński UGDF requires a separate discussion. As an example in Fig.5 we show the dependence of the azimuthal correlations for $p_{1,t}, p_{2,t} \in (5, 15) \text{ GeV}$. We show the result for different values of the parameter b_0 describing initial (for QCD evolution) nonperturbative distribution of gluons in nucleons as well as for different values of the scale parameter μ^2 . The results can be characterized as follows. The smaller b_0 , the bigger the decorrelation between c and \bar{c} . On the other hand, the decorrelation increases with raising μ^2 . Physically one would expect $\mu^2 = \mu^2(p_{1,t}, p_{2,t})$. A reasonable choice would be

$$\mu^2(p_{1,t}, p_{2,t}) = C_1 m_c^2 + C_2 (p_{1,t}^2 + p_{2,t}^2), \quad (3.1)$$

where $C_1, C_2 \sim 1$ may be expected. This would require a use of running scale instead a fixed one as at present. In the moment this was not possible technically and therefore only typical values of

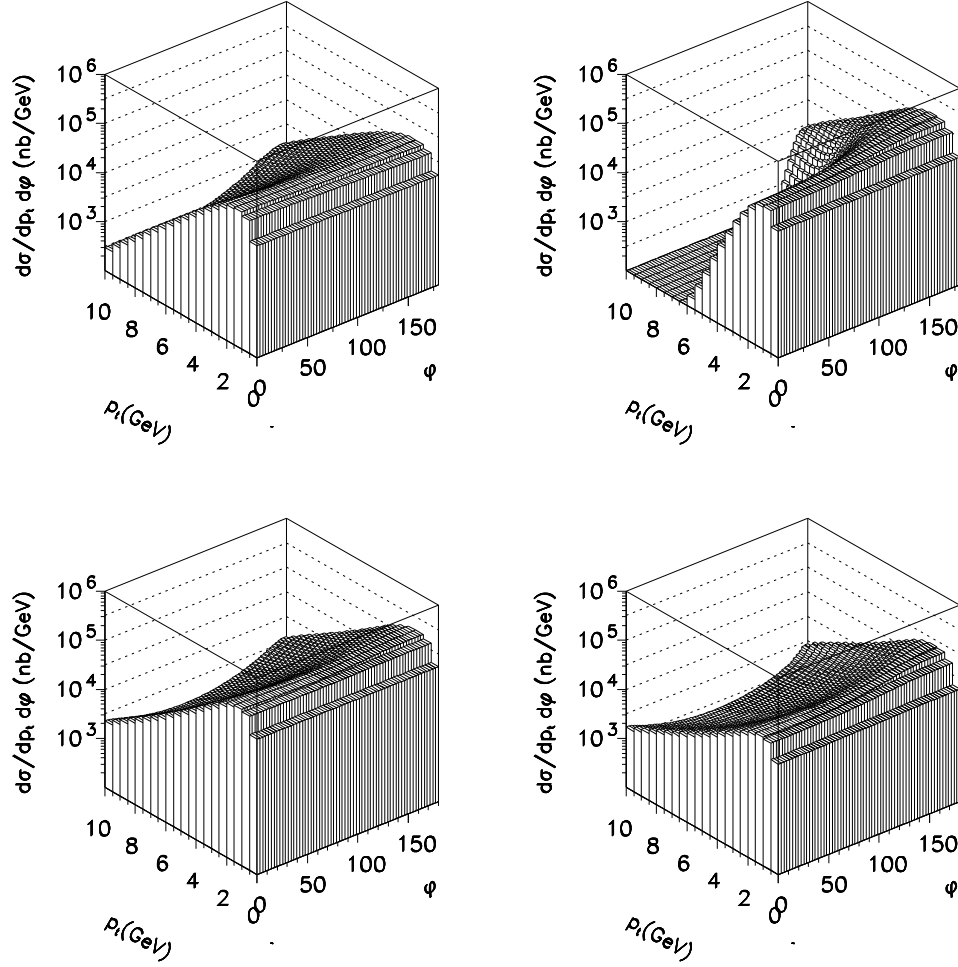


Figure 4: Two dimensional distributions in p_t and ϕ for KMR, Kwieciński ($b_0 = 1 \text{ GeV}^{-1}$, $\mu^2 = 10 \text{ GeV}^2$), BFKL, KL for $W = 1960 \text{ GeV}$.

the scales were taken (see Fig.5). The scale $\mu^2 = 100 \text{ GeV}^2$ is justified by the averaged values of the momenta in our calculation $\langle p_{1,t}^2 \rangle, \langle p_{2,t}^2 \rangle \approx 100 \text{ GeV}^2$. The figure shows that QCD evolution embedded in the Kwieciński equations leads to a strong extra decorrelation of c and \bar{c} in addition to that of the nonperturbative origin as encoded in the parameter b_0 .

It was predicted for jet-jet correlations some time ago that a large rapidity gap between jets leads to increased decorrelation in azimuth. Can one expect a similar interesting effect for $c\bar{c}$ correlations? In Fig.6 we show our result for $c\bar{c}$ correlations as a function of the rapidity gap between c and \bar{c} . Of course, the bigger rapidity distance between c and \bar{c} the smaller the cross section. However the shape of the distribution in azimuth stays practically the same, except at $\Delta y \approx 0$, where a singularity for collinear quark and antiquark emissions shows up.

Finally we wish to come to azimuthal correlations of t and \bar{t} . Such an analysis seems possible even at present at the Tevatron. In Fig.7 we show the azimuthal correlation function for two

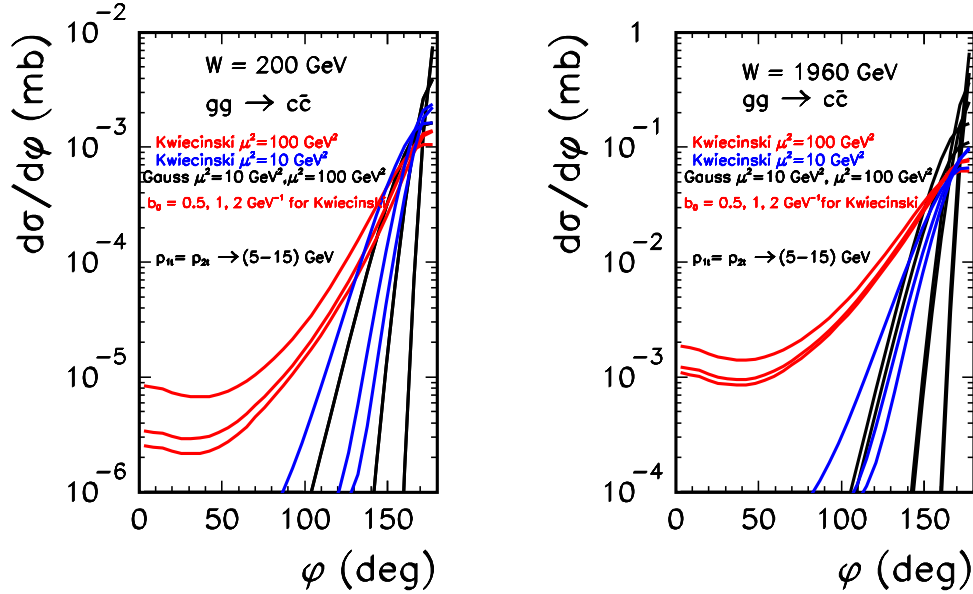


Figure 5: (Color on-line) The azimuthal correlations for the $gg \rightarrow c\bar{c}$ for RHIC and Tevatron energy with the Kwieciński UGDFs for different values of the nonperturbative parameter b_0 (0.5 GeV^{-1} , 1 GeV^{-1} , 2 GeV^{-1}) and for different evolution scales $\mu^2 = 10 \text{ GeV}^2$ (blue line) and $\mu^2 = 100 \text{ GeV}^2$ (red line). The initial distributions (without evolution) are shown for reference by black lines.

energies: $W = 1960 \text{ GeV}$ (Tevatron) and $W = 14\,000 \text{ GeV}$ (LHC). We show separately two contributions: $gg \rightarrow t\bar{t}$ (red) and $q\bar{q} \rightarrow t\bar{t}$ (black). While at the Tevatron energy the $q\bar{q} \rightarrow t\bar{t}$ contribution dominates over the $gg \rightarrow t\bar{t}$ contribution, the situation reverses at the LHC energy where the $gg \rightarrow t\bar{t}$ is the dominant contribution. The shape of both components is, however, very similar.

It would be very interesting to compare the result obtained with in the k_t -factorization approach here with the result of the NLO collinear-factorization approach. The work in this direction is in progress.

4. Summary and outlook

Summarizing, we have discussed the (heavy quark) – (heavy antiquark) correlations in proton-proton and proton-antiproton collisions within the k_t -factorization approach. Different unintegrated gluon distributions have been used in the calculation. The results for azimuthal angle as well as in $p_{1,t} \times p_{2,t}$ correlations have been presented.

In principle, corresponding experimental results would provide new information and could test the unintegrated gluon distributions from the literature. In practice, this could be more difficult as one measures rather heavy mesons or charged leptons from the decays and only correlations of such objects can be studied. However, both heavy mesons and charged leptons from the decays "remember" to large extend the direction of initial heavy quark/antiquark.

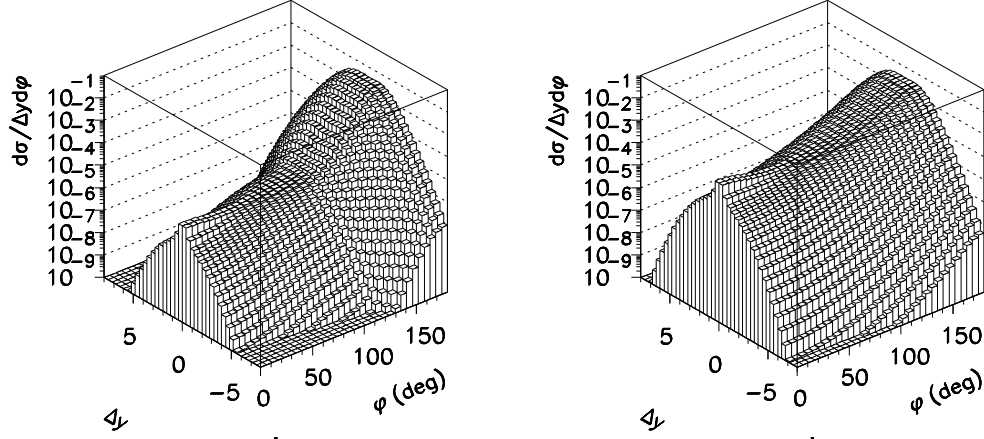


Figure 6: $d\sigma/d\phi$ versus rapidity gap between c and \bar{c} for $W = 1960 \text{ GeV}^2$. ($p_{1,t} = p_{2,t} \rightarrow (5, 15) \text{ GeV}$, $\Delta y = y_1 - y_2$, $\mu^2 = 10 \text{ GeV}^2$ (left panel), $\mu^2 = 100 \text{ GeV}^2$ (right panel).

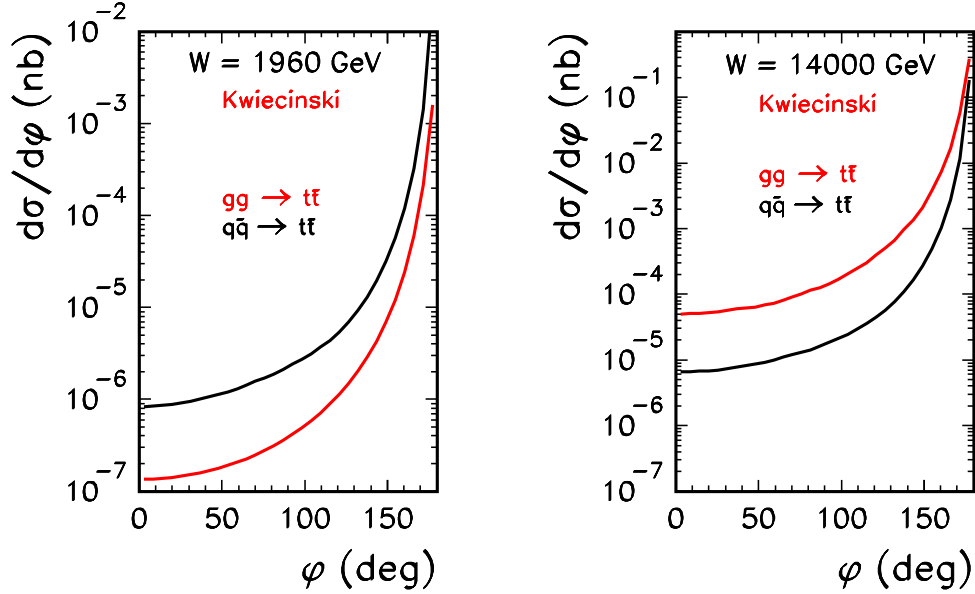


Figure 7: (Color on-line) $d\sigma/d\phi$ for $t\bar{t}$ production at $W = 1960 \text{ GeV}$ (left panel) and $W = 14000 \text{ GeV}$ (right panel) for two process: $gg \rightarrow t\bar{t}$ and $q\bar{q} \rightarrow t\bar{t}$ for Kwieciński distributions. In this calculation $\mu^2 = 10000 \text{ GeV}^2$.

On the theoretical side, a relation between k_t -factorization and standard NLO approaches should be better understood and clarified.

We expect exciting future studies of $Q\bar{Q}$ correlations at the LHC, especially for $t\bar{t}$ where de-

tailed studies will be possible for the first time in the history.

Acknowledgments This work was partially supported by the grant of the Polish Ministry of Scientific Research and Information Technology number 1 P03B 028 28.

References

- [1] S. Catani, M. Ciafaloni and F. Hautmann, Nucl. Phys. **366** (1991) 135.
- [2] J.C. Collins and R.K. Ellis, Nucl. Phys. **B360** (1991) 3.
- [3] R.D. Ball and R.K. Ellis, J.H.E.P. **0105** (2001) 053.
- [4] D. Kharzeev and E. Levin, Phys. Lett. **B523** (2001) 79.
- [5] K. Golec-Biernat and M. Wüsthoff, Phys. Rev. **D60** (1999) 114023-1.
- [6] M.A. Kimber, A.D. Martin and M.G. Ryskin, Eur. Phys. J. **C12** (2000) 655;
M.A. Kimber, A.D. Martin and M.G. Ryskin, Phys. Rev. **D63** (2001) 114027-1.
- [7] M. Łuszczak and A. Szczurek, Phys. Rev. **D73** (2006) 054028.